

**CALCIUM SULFATE IN ATACAMA DESERT BASALT: A POSSIBLE ANALOG FOR BRIGHT MATERIAL IN ADIRONDACK BASALT, GUSEV CRATER.** B. Sutter<sup>1</sup>, D.C. Golden<sup>2</sup>, R. Amundson<sup>3</sup>, G. Chong-Diaz<sup>4</sup>, D.W. Ming<sup>5</sup>. <sup>1</sup>Jacobs-NASA/JSC, [brad.sutter-2@nasa.gov](mailto:brad.sutter-2@nasa.gov); <sup>2</sup>Barrios-NASA/JSC; <sup>3</sup>Ecosystems Div., UC Berkeley; <sup>4</sup>U. Catolica del Norte, Antofagasta, Chile; <sup>5</sup>NASA/JSC.

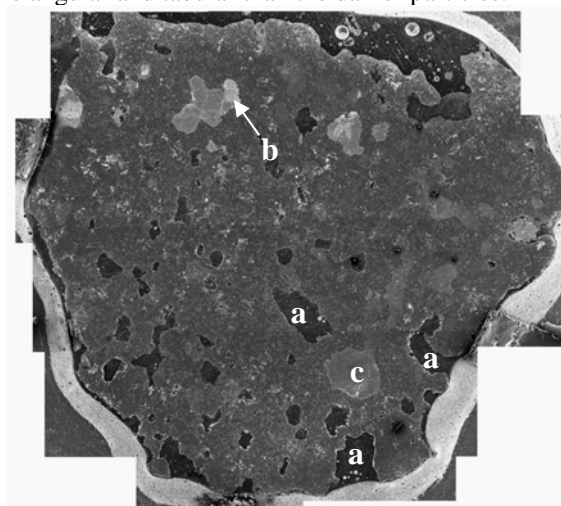
**Introduction:** The Atacama Desert in northern Chile is one of the driest deserts on Earth ( $< 2\text{mm y}^{-1}$ ). The hyper-arid conditions allow extraordinary accumulations of sulfates, chlorides, and nitrates in Atacama soils [1,2]. Examining salt accumulations in the Atacama may assist understanding salt accumulations on Mars. Recent work examining sulfate soils on basalt parent material observed white material in the interior vesicles of surface basalt. This is strikingly similar to the bright-white material present in veins and vesicles of the Adirondack basalt rocks at Gusev Crater which are presumed to consist of S, Cl, and/or Br [3,4]. The abundance of soil gypsum/anhydrite in the area of the Atacama basalt suggested that the white material consisted of calcium sulfate ( $\text{Ca-SO}_4$ ) which was later confirmed by SEM/EDS analysis. This work examines the  $\text{Ca-SO}_4$  of Atacama basalt in an effort to provide insight into the possible nature of the bright material in the Adirondack basalt of Gusev Crater. The objectives of this work are to (i) discuss variations in  $\text{Ca-SO}_4$  crystal morphology in the vesicles and (ii) examine the  $\text{Ca-SO}_4$  interaction(s) with the basalt interior.

**Materials and Methods:** Basalt cobbles (7-25 cm) were sampled at the top of a small hill in the Atacama Desert near the abandoned mining town of Catalina, Chile. A thin section from one of the basalt cobbles was prepared which consisted of the outer rock surface inwards to a depth of 17 mm. The thin-section was examined by an JEOL 5910LV scanning electron microscope (SEM) (15 keV). Energy dispersive spectroscopy (EDS) provided chemical information on the thin section.

**Results:** Surface basalt cobbles (7-25 cm) broken open with a hammer revealed a bright-white colored material on the inside of the rocks. The white material was concentrated near the surface of the rock, but was found as deep as 5 cm into the basalt interior. Thin section SEM imaging showed empty vesicles as well as vesicles filled with bright material (Fig. 1). Letters *b* and *c* denote vesicles filled with  $\text{Ca-SO}_4$  in Fig. 1. EDS analysis indicated that the bright material consists of calcium and sulfate ( $\text{Ca-SO}_4$ ) that is likely gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) and/or anhydrite. Preliminary analysis has indicated that Br or Cl do not exist in significant quantities with the  $\text{Ca-SO}_4$  material. Fine grained ( $< 2\mu\text{m}$ ) clays have yet to be detected in the  $\text{Ca-SO}_4$

matrix. EDS analysis indicates that the main basalt mineral phases are plagioclase feldspar, pyroxene (pigeonite) and ilmenite (Fig. 2). Olivine or magnetite were not detected.

The brightness of the  $\text{Ca-SO}_4$  material varies in the secondary electron mode (Fig. 1; see *b* and *c*). Closer examination indicates that the darker  $\text{Ca-SO}_4$  is more consolidated than the brighter  $\text{Ca-SO}_4$  (Fig. 3). Both bright and dark material have individual particles that are fused together; however, the brighter particles are more angular and tabular than the darker particles.



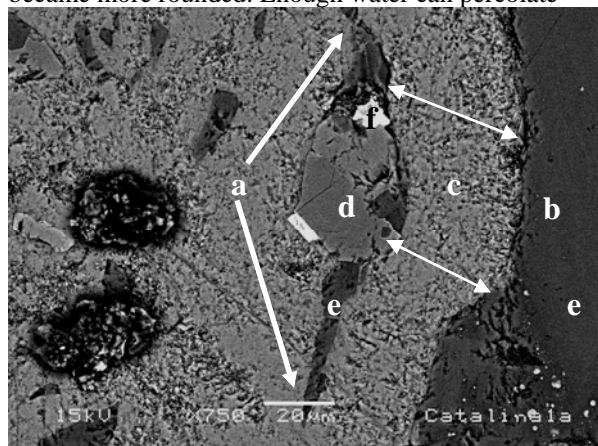
**Fig. 1.** A mosaic of secondary electron images of the vertical thin section of Atacama Desert basalt. Rock surface at top. Thin section is 17 mm high. Representative empty vesicles and brighter and darker  $\text{Ca-SO}_4$  filled vesicles are indicated by (a), (b), and (c), respectively.

The darker material is also more rounded (Fig. 3). This thin section indicates that the brighter/angular  $\text{Ca-SO}_4$  occurs near the surface of this rock. More rocks will be examined to determine if this trend is common to all rocks or if the brighter material can occur deeper in the rock.

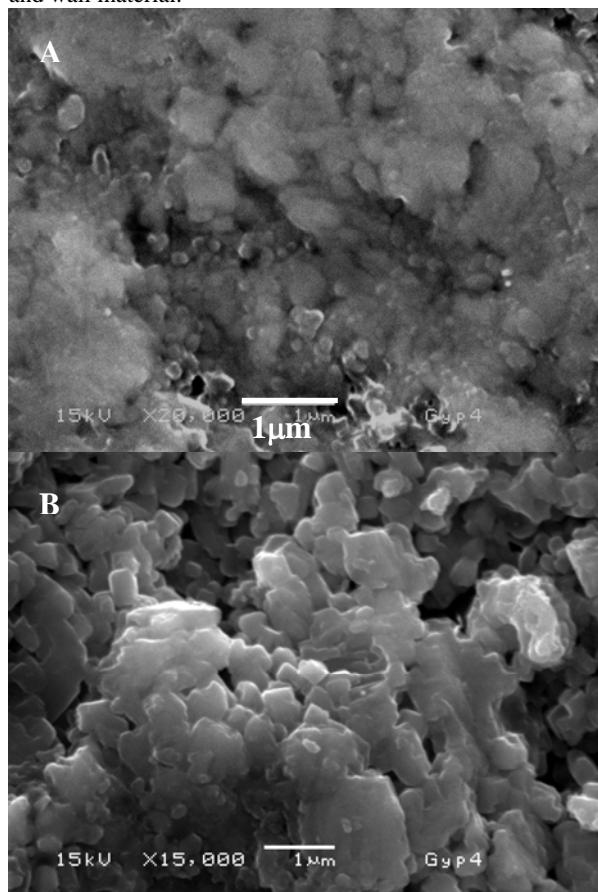
The  $\text{Ca-SO}_4$  causes physical weathering of the vesicle walls by prying or breaking basalt material away from vesicle walls (Fig. 2). Once material is in the  $\text{Ca-SO}_4$  matrix the basalt material is further broken apart by  $\text{Ca-SO}_4$  (data not shown).

**Discussion:** The presence of the angular and rounded morphologies suggest that angular morphology may form first and that through multiple dissolu-

tion/reprecipitation sequences the  $\text{Ca-SO}_4$  material became more rounded. Enough water can percolate



**Fig. 2.** Backscattered electron image of basalt material (a) that has separated from vesicle wall (b) by  $\text{Ca-SO}_4$  (c). Pigeonite (d), ilmenite (e), and plagioclase feldspar (f). Double ended arrows indicate corresponding features of separated and wall material.



**Fig. 3.** Secondary electron images of A. dark/rounded and B. bright/angular  $\text{Ca-SO}_4$  material that correspond to letters c and b in Fig. 1, respectively.

through the basalt vesicles to dissolve but not leach the  $\text{Ca-SO}_4$  from the basalt. The  $\text{Ca-SO}_4$  remains after a wetting event and then evaporation allows for reprecipitation. Sources of water include episodic precipitation and possibly dew which has been observed at other sites in the Atacama [5]. Episodic aqueous activity in the Atacama may mimic the episodic nature of aqueous activity that had once occurred on Mars or that may be occurring to this day [6]. Therefore, similar salt dissolution/reprecipitation processes may have or are occurring in Mars basalt.

The  $\text{Ca-SO}_4$  in the basalt vesicles also appears to physically weather the basalt from the inside. Pressure is exerted by  $\text{Ca-SO}_4$  entering the cracks lining the vesicle walls. Eventually,  $\text{Ca-SO}_4$  causes wall material to break away.  $\text{Ca-SO}_4$  also enters into cracks in the separated basalt grains causing grains to break apart in the  $\text{Ca-SO}_4$  matrix. The wet/dry process assists physical weathering by causing corresponding expansion of the  $\text{Ca-SO}_4$  material causing cracks to enlarge.

The mineralogy of the  $\text{Ca-SO}_4$  material may be gypsum and/or anhydrite since these are the only  $\text{Ca-SO}_4$  mineralogies found in the soils at this site. Significant levels of Cl or Br have not been detected in the  $\text{Ca-SO}_4$  matrix. The highest Br concentration in the soil was 4 ppm while Cl concentrations reached 0.5 wt%. Elevated Cl concentrations may be found with  $\text{Ca-SO}_4$  with further investigations. The large amount of  $\text{Ca-SO}_4$  in the basalt suggests an outside source that may be marine aerosols and/or continental dust [7]. Isotope work will be required to determine the sources of the  $\text{Ca-SO}_4$  material. No clays have been initially detected in the  $\text{Ca-SO}_4$  matrix. Further work will either detect clays or provide insight as to why clays are not found in the  $\text{Ca-SO}_4$  matrix. The thin (<1mm) weathering rind of Atacama basalt will also be examined to assess rind formation and rind interactions with  $\text{Ca-SO}_4$  under hyper-arid conditions as applicable to Mars.

The chemistry/mineralogy of the bright materials in the Adirondack basalt and Atacama basalt may be comparable. Results from this work have provided insight to possible salt-rock processes that have or may be occurring in martian rocks.

**References:** [1] Ericksen G.E. (1981) *Geol. Surv. Prof. Paper 1188*. [2] Ewing S.A. et al. (2006) *Geochim. Cosmochim. Acta*, 70, 5292. [3] McSween et al. (2006) *JGR*, 111, E2S10. [4] Haskin et al. (2005) *Nature*, 436, 66. [5] McKay et al. (2003) *Astrobio.*, 3, 393. [6] Malin et al. (2006) *Science*, 314, 1573. [7] Rech et al. (2003). *Geochim. Cosmochim. Acta* 67, 575.